NASA PEMFC Development Background and History

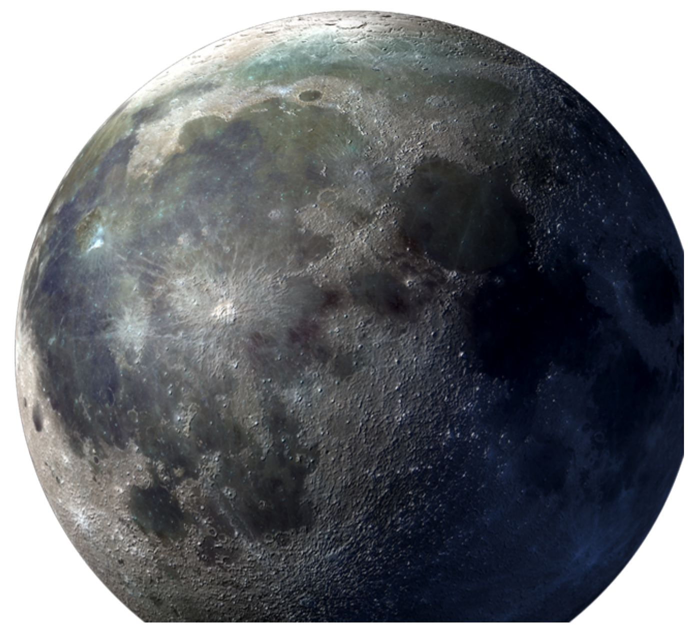
NASA has been developing proton-exchange-membrane (PEM) fuel cell power systems for the past decade, as an upgraded technology to the alkaline fuel cells which presently provide power for the Shuttle Orbiter. All fuel cell power systems consist of one or more fuel cell stacks in combination with appropriate balance-of-plant hardware. Traditional PEM fuel cells are characterized as flow-through, in which recirculating reactant streams remove product water from the fuel cell stack. NASA recently embarked on the development of non-flow-through fuel cell systems, in which reactants are dead-ended into the fuel cell stack and product water is removed by internal wicks. This simplifies the fuel cell power system by eliminating the need for pumps to provide reactant circulation, and mechanical water separators to remove the product water from the recirculating reactant streams. By eliminating these mechanical components, the resulting fuel cell power system has lower mass, volume, and parasitic power requirements, along with higher reliability and longer life.

Four vendors have designed and fabricated non-flow-through fuel cell stacks under NASA funding. One of these vendors is considered the "baseline" vendor, and the remaining three vendors are competing for the "alternate" role. Each has undergone testing of their stack hardware integrated with a NASA balance-of-plant. Future Exploration applications for this hardware include primary fuel cells for a Lunar Lander and regenerative fuel cells for Surface Systems.

NASA PEMFC Development Background and History

Mark A. Hoberecht

National Aeronautics and Space Administration
Glenn Research Center



January 25, 2010
NUWC
Newport, RI

NASA PEMFC Development History

- NASA initiated PEMFC studies during Shuttle upgrade program in late 1990's at JSC
  - High DDT&E costs prevented switch from alkaline to PEM, in spite of several technical advantages

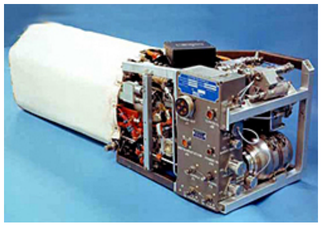
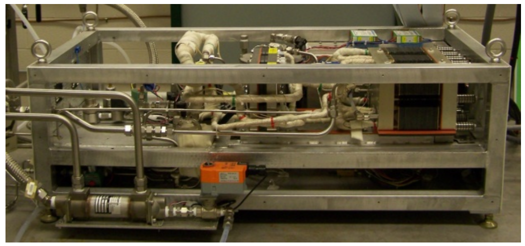
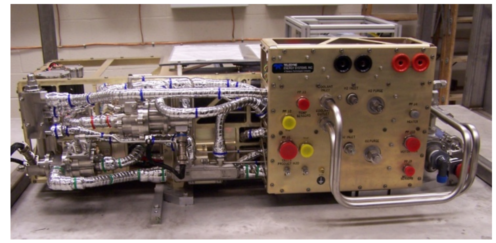
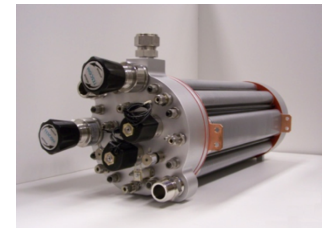
- RLV program funded initial development of PEMFC technology (2001)
  - First vendor was Allied Signal

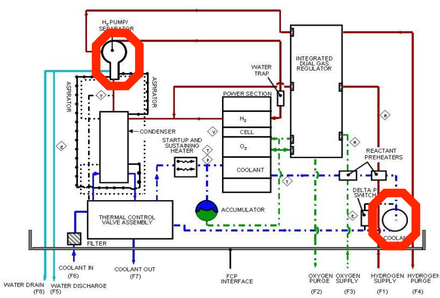
- RLV transitioned into NGLT,SLI, and eventually ETDP programs (2001-2007)
  - ElectroChem and Teledyne selected for Breadboard development
  - Teledyne down-selected for Engineering Model development
  - Disadvantages of flow-through PEMFC systems became evident during testing of Engineering Model; ***balance-of-plant experienced multiple failures***

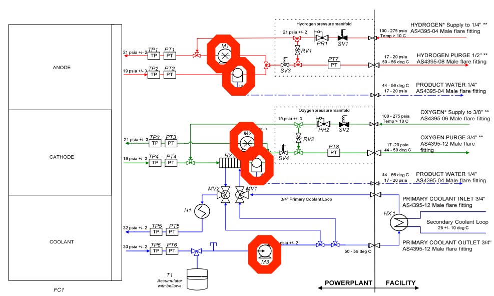
- Began investigation of "passive" balance-of-plant concepts for flow-through technology (2005)
  - Reactant pumps replaced with injectors/ejectors
  - Mechanical water separators replaced with membrane water separators

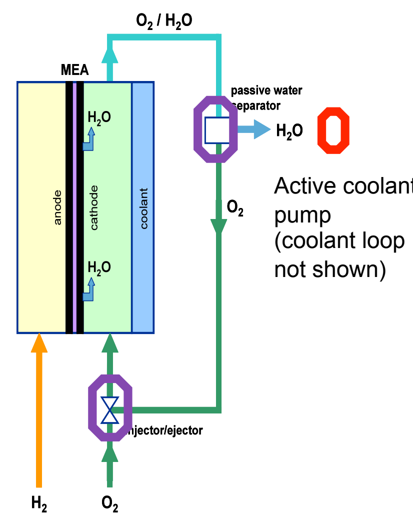
- In parallel, began investigation of non-flow-through technology through SBIR program (2005)
  - ***First vendor was Infinity***

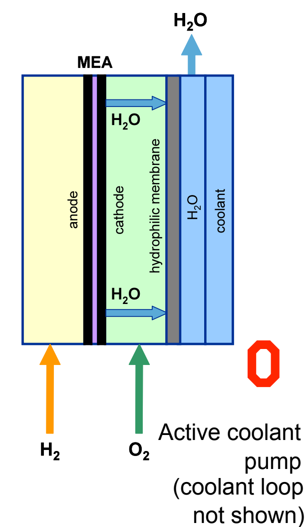
- ***Down-selected to non-flow-through technology over flow-through technology; initiated in-house development of balance-of-plant*** (2008)

Johnson Space Center	Glenn Research Center	Glenn Research Center	Glenn Research Center
Shuttle “Active BOP” Alkaline	**“Active BOP” PEM**	**“Passive BOP” PEM**	**“Passive BOP” PEM**
			
Flow-Through	**Flow-Through**	**Flow-Through**	***Non*-Flow-Through**









= **Active Mechanical Component (pump, active water separator)**

= **Passive Mechanical Component (injector/ejector, passive water separator)**

Fuel Cell Technology Progression to Simpler Balance-of-Plant

Fuel Cell Technical Approach:
"Non-Flow-Through" Water Management

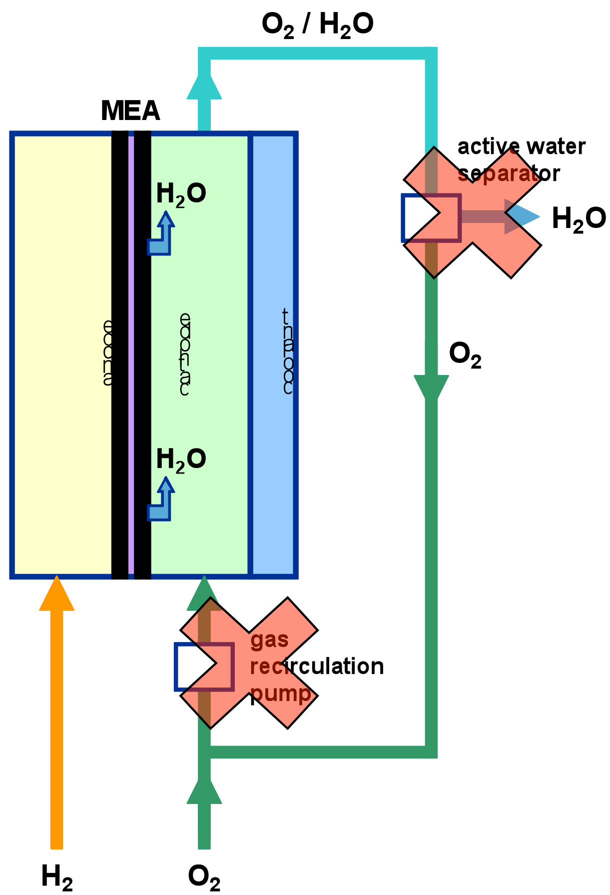
Develop "non-flow-through" proton exchange membrane fuel cell technology to improve system-level mass, volume, reliability, and parasitic power

Flow-Through components eliminated in Non-Flow-Through system include:

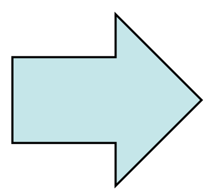
- Pumps or injectors/ejectors for recirculation
- Motorized or passive external water separators

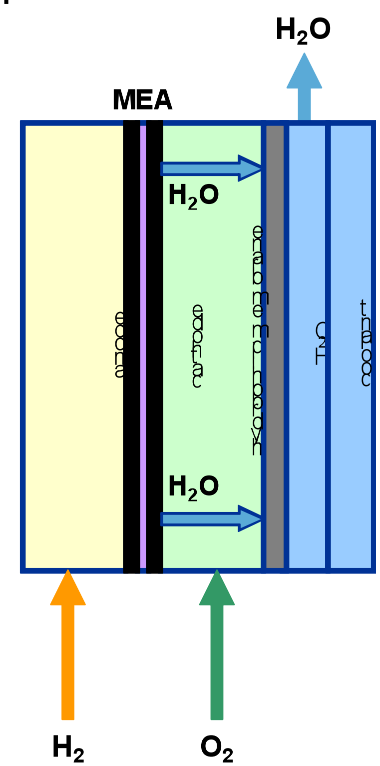
Non-Flow-Through PEMFC technology characterized by dead-ended reactants and internal product water removal

- Tank pressure drives reactant feed; no recirculation
- Water separation occurs through internal cell wicking

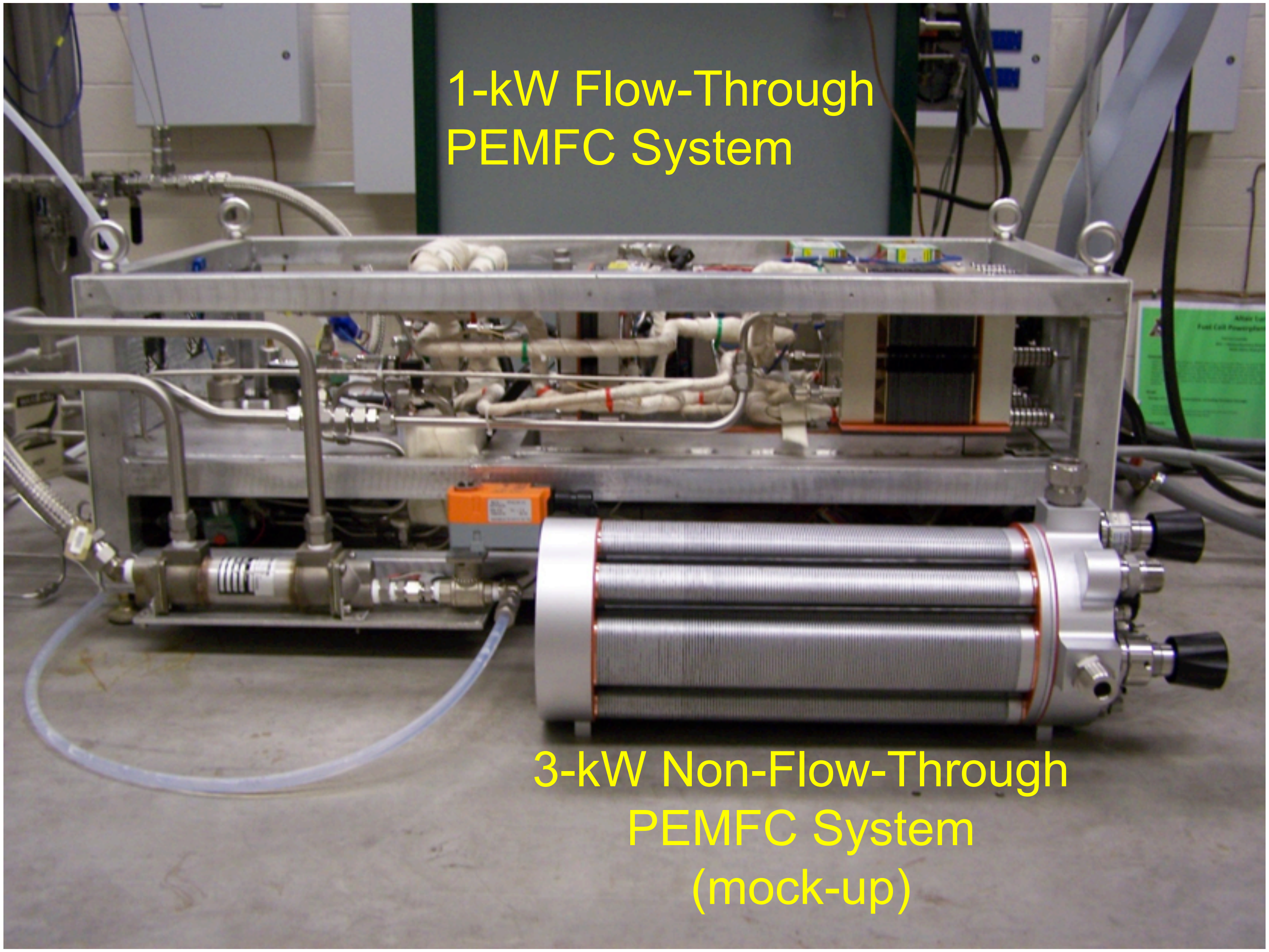


Flow-Through





Non-Flow-Through



Non-flow-through PEMFC system has a substantially simpler balance-of-plant than conventional flow-through PEMFC system.

This offers significant advantages.

System-Level Comparison of Flow-Through vs. Non-Flow-Through PEMFC Technology

Design Parameter	Flow-Through	Non-Flow-Through
Efficiency	–	–
Mass		✓
Volume		✓
Parasitic Power		✓
Reliability		✓
Reactant Utilization		✓
Equivalent Reactant Storage "Depth-of-Discharge"		✓
Life		✓
Cost		✓
TRL	✓	

Non-Flow-Through PEMFC Technology Vendor Comparison

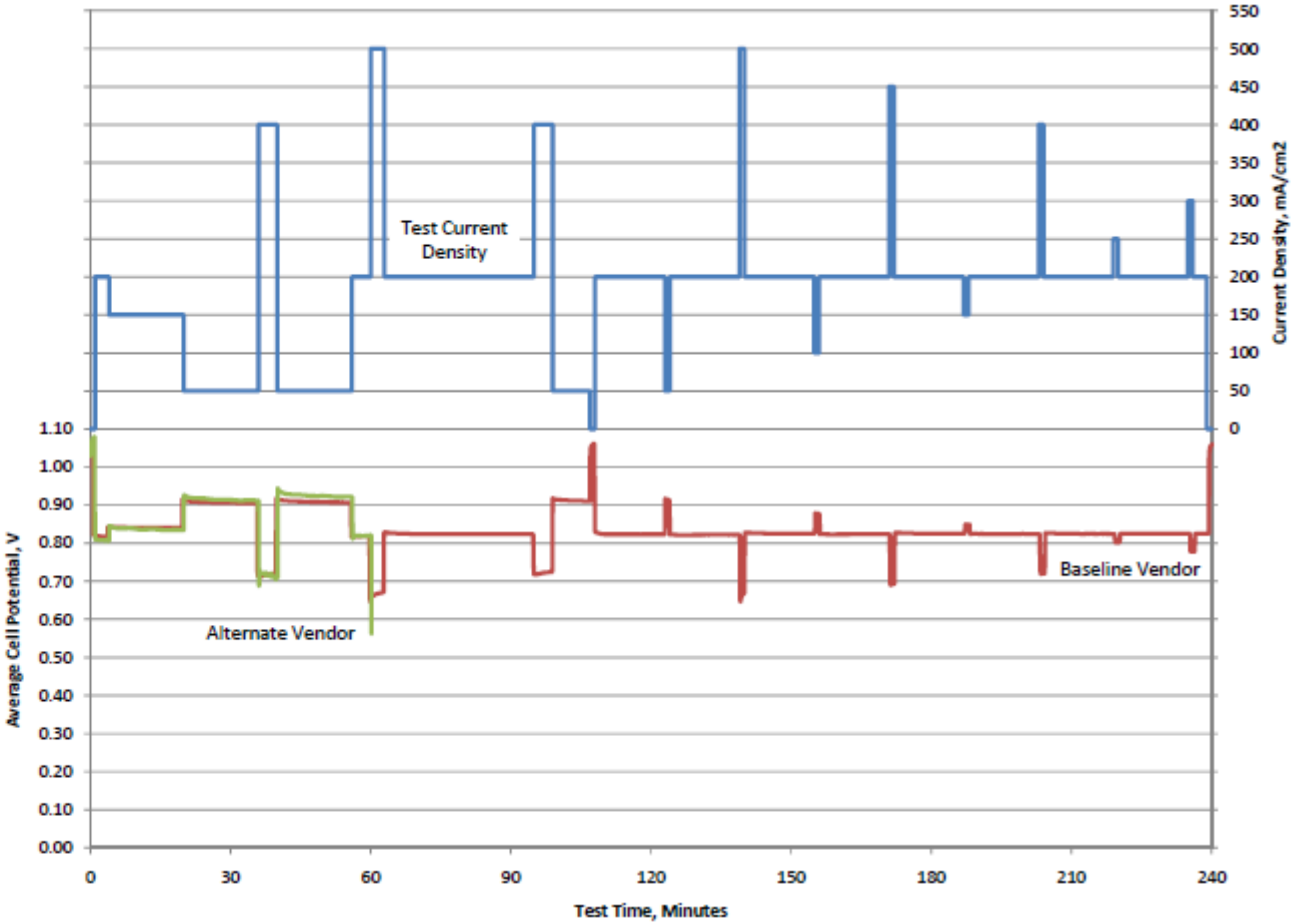
- Infinity selected as “baseline” non-flow-through PEMFC vendor very early in program
  - Awarded very first non-flow-through Phase I SBIR (2005)
  - Demonstrated development success led to Phase II and Phase III contract awards
  - Very advanced and robust cell technology
  - Excellent cell performance
  - Superior water removal
  - Knowledgeable team with extensive flight hardware development experience (Shuttle, Apollo, Gemini)

- Other subsequent SBIR and IPP vendors competed for “alternate” role
  - ElectroChem, Proton, and Teledyne stacks all experienced water management issues
  - ElectroChem most promising “alternate” technology

Non-Flow-Through PEMFC Technology Vendor Comparison

Parameter	Infinity	ElectroChem	Proton	Teledyne
Active Area (cm^2)	50 & 150	200	86	69
Operating Temperature (^oC)	60	75	75	55
Operating Pressure (psig)	30	30	50	10
Max Oxygen/Water ΔP (psig)	8	30	4	5
Pressure Control Sensitivity	Medium	Low	Very High	High
Peak Steady State Current Density (mA/cm^2)	500	350	400	200
Pass Load Profile Test ?	Yes	No	No	No
Orientation Sensitivity	None	TBD	TBD	TBD

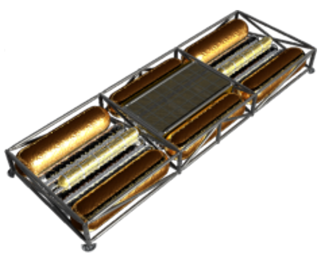
NASA Load Profile Test, Vendor Comparison



Fuel Cell Technology Development
Mission Requirements Assessment

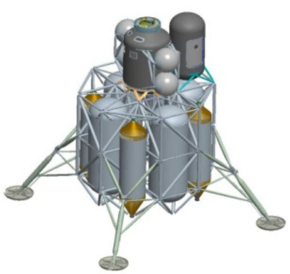
Lunar Architecture Studies identified regenerative fuel cells and rechargeable batteries as enabling technology, where enabling technologies are defined as having:
"overwhelming agreement that the program cannot proceed without them."

<u>Surface Systems</u>



Surface Power: Maintenance-free operation of **regenerative fuel cells** for >10,000 hours using ~2000 psi electrolyzers. Power level TBD (2 kW modules for current architecture)
Reliable, long-duration maintenance-free operation; human-safe operation; architecture compatibility; high specific-energy, high system efficiency.

Mobility Systems: Reliable, safe, secondary batteries and **regenerative fuel cells** in small mass and volume.
Human-safe operation; reliable, maintenance-free operation; architecture compatibility; high specific-energy.



<u>Lander</u>

Descent Stage: Functional **primary fuel cell** with 5.5 kW peak power.
Human-safe reliable operation; high energy-density; architecture compatibility (operate on residual propellants).

Key Performance Parameters for Fuel Cell Technology Development

Customer Need	Performance Parameter	SOA (alkaline)	Current Value* (PEM)	Threshold Value** (@ 3 kW)	Goal** (@ 3 kW)
Altair: 3 kW for 220 hours continuous, 5.5 kW peak. Lunar Surface Systems: TBD kW for 15 days continuous operation Rover: TBD	System power density Fuel Cell RFC (without tanks)	49 W/kg n/a	n/a n/a	88 W/kg 25 W/kg	136 W/kg 36 W/kg
	Fuel Cell Stack power density	n/a	n/a	107 W/kg	231 W/kg
	Fuel Cell Balance-of-plant mass	n/a	n/a	21 kg	9 kg
	MEA efficiency @ 200 mA/cm^2 For Fuel Cell Individual cell voltage For Electrolysis Individual cell voltage For RFC (Round Trip)	 73% 0.90V n/a n/a n/a	 72% 0.89V 86% 1.48 62%	 73% 0.90V 84% 1.46 62%	 75% 0.92V 85% 1.44 64%
	System efficiency @ 200 mA/cm^2 Fuel Cell Parasitic penalty Regenerative Fuel Cell**** Parasitic penalty High Pressure penalty	 71% 2% n/a n/a n/a	 65%*** 10% n/a n/a n/a	 71% 2% 43% 10% 20%	 74% 1% 54% 5% 10%
Maintenance-free lifetime Altair: 220 hours (primary) Surface: 10,000 hours (RFC)	Maintenance-free operating life Fuel Cell MEA Electrolysis MEA Fuel Cell System (for Altair) Regenerative Fuel Cell System	 2500 hrs n/a 2500 hrs n/a	 13,500 hrs n/a n/a n/a	 5,000 hrs 5,000 hrs 220 hrs 5,000 hrs	 10,000 hrs 10,000 hrs 220 hrs 10,000 hrs

*Based on limited small-scale testing.

**Threshold and Goal values based on full-scale (3 kW) fuel cell and RFC technology.

***Teledyne passive flow through with latest MEA

****Includes high pressure penalty on electrolysis efficiency 2000 psi

1-cell 50 cm^2 active area | 4-cell | 4-cell with flat-plate heat pipes | 4-cell with advanced manufacturing | 4-cell with improved performance | 4-cell 150 cm^2 active area

Infinity Non-Flow-Through Fuel Cell Stack Progression